BIOSTABILIZATION OF CAFETERIA WASTE BY TAKAKURA HOME METHOD

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by

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LIST OF ABBREVIATIONS

AC	Actinomycetes
ANOVA	Analysis of variance
APHA	American Public Health Association
CFU	Colony-forming units
CW	Cafeteria waste
DOC	Dissolved organic carbon
EC	Electrical conductivity
EM	Effective Microorganisms
EPU	Economy Planning Unit
EU	European Union
FAO	Food and Agriculture Organization, United Nations
FSC	Food supply chain
FTIR	Fourier transform infrared spectroscopy
FW	Food waste
HA	Humic acid
IGES	Institute for Global Environmental Strategies
IMO	Indigenous Microorganisms
KITA	Kitakyushu International Techno-cooperative Association
MC	Moisture content
MSW	Municipal Solid Waste
RB	Rice bran
RH	Rice husk

SA	Solution A
SB	Solution B
SEA	South East Asia
SW	Solid waste
SWM	Solid waste management
T_1	Reactor with *tempeh* as microbial starter
T_2	Reactor with *tempoyak* as microbial starter
T_3	Reactor with *tapai pulut* as microbial starter
C	Control with cow manure as microbial starter
TB	Total bacteria
C	Carbon
TF	Total Fungi
THM	Takakura Home Method
N	Nitrogen
TOC	Total organic carbon
U.S.	United States
UV	Ultraviolet

LIST OF SYMBOLS

C	carbon
CFU/g	colony-forming units/gram of compost
CH_4	methane (g)
CHNS/O	carbon-hydrogen-nitrogen-sulphur/oxygen (analyzer)
C:N	carbon: nitrogen (ratio)
CO_2	carbon dioxide
g CO_2 /m^2h	rate of carbon dioxide emission
E	exponential function
H^+	ion of hydrogen
H_2S	hydrogen sulfide
N	nitrogen
NH_3	ammonia
NH_4NO_3	ammonium nitrate
O_2	oxygen
pH	scale, measure of acidity or basicity of aqueous solution
T_1	reactor T_1
T_2	reactor T_2
T_3	reactor T_3
r	Pearson’s correlation coefficient
°C	Celsius (temperature)

BIOPENSTABILAN SISA KAFETERIA MELALUI KAEDAH RUMAH TAKAKURA

ABSTRAK

Eksperimen telah dijalankan untuk mengkaji tahap kematangan dan kestabilan proses biopenstabilan sisa kafeteria dengan menggunakan Kaedah Rumah Takakura (Takakura Home Method). Kaedah THM diadaptasikan daripada Kitakyushu International Techno-Cooperative Association (KITA). Dalam kajian ini, tiga jenis makanan fermentasi tempatan (tempeh, tempoyak dan tapai pulut) digunakan sebagai sumber inokulum mikrob. Tempeh digunakan berdasarkan kehadiran populasi fungi sebagai kumpulan mikroorganisma utama. Fungi memainkan peranan yang penting dalam proses penguraian melalui rangkaian mycelium yang luas untuk mengkolonisasi matrik lignoselulosa bahan organik dan kapasiti enzim yang tinggi untuk menguraikan bahan detritus yang kompleks. Tempoyak dan tapai digunakan berdasarkan kehadiran bakteria asid laktik (LAB) dan yis yang menyekat pertumbuhan patogen dan membolehkan pertumbuhan bakteria termofilik. Empat reaktor penstabilan berdasarkan sumber mikrob yang berbeza telah disediakan; (i) tempeh (T_1), (ii) tempoyak (T_2), (iii) tapai pulut (T_3), dan tinja lembu (kawalan). Sisa kafeteria digunakan sebagai sumber kajian dan proses biopenstabilan diperhatikan selama 28 hari. Dapatan kajian menunjukkan bahawa pertumbuhan mikrob berdasarkan jumlah bakteria (TB), jumlah fungi (TF) dan aktinomiset (AC) meningkat di peringkat akhir penyediaan kultur mikrob dalam keempat-empat reaktor dan paling rendah dalam sistem kawalan. Kematangan proses biopenstabilan dinilai dengan menggunakan suhu, pH, analisis unsur karbon, nitrogen dan C:N. Suhu tertinggi untuk T_1, T_2, T_3 dan kawalan telah dicatatkan pada 43 °C, 47.8 °C,

45.3 °C dan 41 °C masing-masing. Kematangan proses biopenstabilan ditunjukkan oleh perubahan suhu dan pengurangan suhu reaktor secara beransur-ansur ke nilai ambien. Nilai pH tertinggi dalam kesemua reaktor telah dicatatkan pada minggu ke-4 apabila pemerhatian proses biopenstabilan ditamatkan (T_1 = 7.17 ± 0.03, T_2 = 7.07 ± 0.03, T_3 = 7.37 ± 0.03, kawalan = 7.47 ± 0.03). Kematangan proses biopenstabilan ditunjukkan oleh peningkatan nilai pH ke nilai hampir neutral dan stabil. Pada minggu ke-4, C:N dalam semua reaktor telah dicatakan pada 13.17 ± 0.16% (T_1), 10.59 ± 0.96 (T_2), 14.29 ± 0.70 (T_3) dan 10.78 ± 0.77% (kawalan) masing-masing. Kematangan proses biopenstabilan ditunjukkan oleh penurunan bacaan C:N ke linkungan di antara 10 dan 15. Kestabilan proses biopenstabilan dinilai menggunakan unit colony-forming units (CFU) TB, TF, AC dan evolusi CO_2. Dapatan kajian menunjukkan bahawa bacaan CFU tertinggi TB dan TF telah dicatatkan pada minggu 0-1 dan berkurangan secara beransur-ansur. Bacaan tertinggi AC dicatatkan pada peringkat lebih lewat daripada TB dan TF (minggu 1-2). Kadar evolusi CO_2 tertinggi dalam kesemua reaktor telah dicatatkan pada minggu 0 dan berkurang secara beransur-ansur. Secara keseluruhannya, kestabilan proses biopenstabilan ditunjukkan oleh pengurangan biomas mikrob dan evolusi CO_2. Analisis variasi (p = 0.05) menunjukkan bahawa terdapat perbezaan yang signifikan dalam pertumbuhan TB, TF dan AC di antara reaktor THM dan kawalan. Analisis korelasi Pearson menunjukkan bahawa tedapat korelasi yang signifikan di antara evolusi CO_2, C:N dan populasi mikrob.

BIOSTABILIZATION OF CAFETERIA WASTE BY TAKAKURA HOME METHOD

ABSTRACT

An experiment was designed to evaluate the degree of maturity and stability in the biostabilization of cafeteria waste using Takakura Home Method (THM). THM method was adapted from Kitakyushu International Techno-Cooperative Association (KITA). In the present study, three local fermented food products (*tempeh*, *tempoyak* and *tapai pulut*) were used as microbial starters. *Tempeh* was selected based on its predominance of fungal population. Fungi play a crucial role in the decomposition process due to its extensive network of mycelium to colonize the lignocellulose matrix in organic matter, and its high enzymatic capacities to decompose recalcitrant detritus materials. *Tempoyak* and *tapai* were used based on the presence of lactic acid bacteria (LAB) and yeast that suppres the growth of pathogens and enable the growth of thermophilic bacteria. There were four reactors with different microbial starters; (i) *tempeh* (T_1), (ii) *tempoyak* (T_2), (iii) *tapai pulut* (T_3) and cow manure (control). Cafeteria waste was used as the feed material and biostabilization process was observed for 28 days. Findings indicated that the microbial growth of total bacteria (TB), total fungi (TF) and actinomycetes (AC) increased in the final stage of microbial seeding preparation in all four reactors and was the lowest in control. The maturity of the biostabilization process was evaluated using temperature, pH, elemental analysis of carbon, nitrogen and C:N. Highest temperatures for T_1, T_2, T_3 and control were recorded at 43°C, 47.8°C, 45.3°C and 41°C respectively. Maturity of the biostabilization process was indicated by temperature changes and gradual decrease of temperature towards ambient temperature. The pH values for all reactors were the highest in week 4 when the biostabilization process had been terminated

(T_1=7.170.03, T_2=7.070.03, T_3=7.370.03, control=7.470.03). Maturity of the biostabilization process was indicated by the increase of pH values to near neutral, stable pH range. In week 4, C:N in all reactors were recorded at 13.17 ± 0.16% (T_1), 10.59 ± 0.96 (T_2), 14.29 ± 0.70 (T_3) and 10.78 ± 0.77% (control) respectively. Maturity of the biostabilization process was indicated by a gradual decrease of C:N to the range of 10 to 15. The stability of the biostabilization process was evaluated using colony-forming units (CFU) of TB, TF, AC and CO_2 evolution. Findings showed that TB and TF reached peak population in week 0-1 followed by a gradual decline as the biostabilization process proceeded. The peak population of AC occurred at a later stage than TB and TF (week 1-2). The highest CO_2 evolution rates in all reactors were recorded in week 0 and subsequently decreased. The stability of the biostabilization process was indicated by a decrease of microbial biomass and CO_2 evolution. Analysis of variance ($p=0.05$) showed that there were significant differences in the growth of TB, TF and AC between THM reactors and control. Using Pearson's Correlation Test, significant correlations between CO_2 evolution, C:N and microbial population during the biostabilization process were indicated.

CHAPTER 1

INTRODUCTION

1.0 Introduction

The first chapter of the thesis covers the following subsections: Research background, problem statement of research, research objectives and the scope of the study. In the research background, Takakura Home Method (THM) is being introduced as a local knowledge-based composting method based on the incorporation of local knowledge and the adaptive use of local resources in the method for communities to manage their own wastes at the regional scale. Also presented in the subtopic is the method's history, implementation and its mechanisms in utilizing indigenous microorganisms cultured from local fermented food products as microbial inoculums to enhance the biostabilization process of municipal organic waste.

In the problem statement, the relevance of THM as a method to manage organic solid waste in Malaysia is discussed. Statistics that show the proportion of food and organic waste from the total solid waste generated and the existing solid waste management practices in Malaysia are presented. Due to the high proportion of organic waste and landfill as the main practice in the disposal of solid waste, the relevance of THM composting as an alternative solid waste management is stated. Three specific research objectives are developed to determine the feasibility of THM as a composting method based on the microbial profile during the biostabilization of cafeteria waste and the maturity and stability of the stabilized waste. In the research scope, the use of cafeteria waste as the compost feed and the types of fermented food products used as microbial sources are presented.

1.1 Research background

Globally, the use of local knowledge in environmental management is gaining recognition and attention among researchers. For example, previous study has been conducted on the indigenous system known as “ekwar” used in managing the ecosystem and natural resources of the Turkwel Riverine Forest in Kenya, and the implementation of local fishing practices in a Swedish community to prevent the overfishing of crayfish (Raymond et al., 2010). The emergence of the local knowledge in environmental management is due to diverse interpretations of the physical environment based on different cultural perspectives from around the world. Even though scientific knowledge held the central role in academic research, the importance of other knowledge systems such as local or traditional knowledge in tackling regional environmental problems cannot be disputed. Previous studies have suggested that the incorporation of local knowledge unravels complex ecological management and develops sustainable management in environmental management (Mazzocchi, 2006).

Local knowledge in the context of environment management refers to a systematic body of knowledge acquired by different groups of indigenous people through the accumulation of experiences and understanding of the environment through observations. Given this, traditional or local knowledge can thus be defined as a branch of knowledge developed regionally and is unique to a given society or culture. There are many benefits associated with the incorporation of local knowledge in environmental management. As they are often founded on observations over a long period of time and incorporate extensive fields of study, the implementation of local knowledge is often practical, and the results are demonstrative (Folke, 2004).

Takakura Home Method (THM) is local knowledge-based composting method based on its adaptive use of resources available in the local region and its embedment in the community's practices to manage their own wastes. THM is firstly implemented in Surabaya, Indonesia's second largest city in 2004. The method is the result of a cooperative research conducted between PUSDAKOTA (Surabaya) and Kitakyushu International Techno-cooperative Association, KITA (Japan) lead by Mr. Koji Takakura, an environmental engineer from Jpec Co. Ltd. PUSDAKOTA (the abbreviation of *Pusat Pemberdayaan Komunitas Perkotaan Universitas Surabaya*) is also known as the Center of Urban Community Empowerment. It is a non-profit institution established by the University of Surabaya in 2 November 2000 with different socioeconomic agendas to empower the community and provides opportunities for them to improve their life qualities. The method was established as part of the institution's agenda in integrated environmental management to solve the problem of municipal solid waste management within the communities of Kampong Rungkut Lor, a village within the city inhabited by approximately 1200 families (PUSDAKOTA, 2013).

The project was carried out with the aim to reduce waste generation by about 30% in four years through collaboration between international environment cooperation (Kitakyushu International Techno-cooperative Association, KITA and Institute for Global Environmental Strategies, IGES) and the municipality of Surabaya (Premakumara, 2013). Under the initiative, communities are engaged in waste segregation and composting by using THM as one of the composting methods.

As the result, 100% of organic waste generated by the community is collected and composted and produces about 40 tonnes of compost monthly. From the proceeds generated by the compost, 10% is returned to the village in the form of cash (3R Knowledge Hub). Following the success in Surabaya, this method has since been implemented widely around the regions of South East Asia (SEA) as a mean of solving problems associated with SWM with the participation of respective municipalities in each region (IGES, 2009). This method has been implemented successfully in Bangkok, Thailand, in 2008 and Sibu, Malaysia in 2010 as an initiative to reduce the amount of waste being thrown to the landfill (Chua, 2010).

Composting methods such as THM is usually a more preferred method to manage MSW due to practical and economic reasons. Through composting, the volume of waste could be reduced to 40-50% and results in lower waste transportation cost. The microbial heat generated during the thermophilic phase also enables the destruction of pathogens and produces end products sufficiently stable for storage (Xiao et al., 2009). During composting, carbon and nitrogen compounds are utilized for microbial metabolisms by microorganisms. Biodegradable compounds are rapidly broken down and biostabilized into compost which comprised of humic substances (Wei et al., 2007). Humic substances are the remnants of dead microbial cells and organic compounds with high molecular weights which cannot be degraded by microorganisms. Instead, it is used by some microorganisms as electron acceptors in anaerobic mechanisms (Lovley et al., 1996). Therefore, composting produces end products which are value-added materials due to the important role of humic substances in the ecology of the soil system and as nutrients for plants. However, the main focus of composting is on the improvement of the degradation efficiency through artificial alterations of the composting process (Xi et al., 2005).

One of the methods developed is microbial inoculation or the addition of compost seed. In microbial inoculation, microorganisms are introduced into the composting system to accelerate the degradation process. Similarly, the term "seeding" is used to imply to the introduction of foreign microorganisms into the natural environment for the purpose of increasing the rate or extent of biodegradation (Coyne, 1999). Several studies have demonstrated the positive impact of microbial inoculation on the biodegradation rate of wastes. The roles of microbial inoculation in composting have been identified, such as a more effective decomposition of protein to prevent the drop of initial pH values and stimulates the proliferation of thermophilic bacteria (Choi and Park, 1998); increases the degree of humification and the rate of biodegradation (Xi et al., 2007); provides greater control during composting processes and decreases the accumulation of pathogens in the final product of the biodegradation (Wang et al., 2003); and enhances the degradation of wastes, shortens the maturity period and improves the quality of biofertilizer (Tsai et al., 2007).

In THM composting, indigenous microorganisms cultured from local fermented food products are utilized as microbial inoculums to enhance the biostabilization process of municipal organic waste. Fermentation is one of the oldest ways of food processing and preservation, and fermented food products are widely available in this region. In developing countries in particular, fermented food product is included in the staple diets of local people and contributes mainly as protein sources such as the consumption of *tempeh* (Achi, 2005). Local fermented food such as *tempeh*, *tempoyak*, *tapai pulut*, *taucu* and soy sauce are used as microbial starters in THM composting.

During the preparation of THM compost seed, the microbial starter is mixed into bulking agents comprised of rice bran and rice husk. Rice bran and rice husk are abundant sources of agricultural by-products from rice cultivation in the region of South East Asia. The use of fermented food and agricultural by-products demonstrates an integration of inexpensive method to manage municipal solid waste due to the availability of these materials locally and the omission of the application of mechanical heat and forced aeration in the decomposition process.

In Malaysia, the total solid waste generated comprised of a high proportion of food and organic wastes. In the state of Penang alone, it has been reported in 2012 that organic or food waste made up 57% (% weight) of the total waste generated (Yusoff & Zakaria, 2012). The figure is obtained from a waste composition analysis conducted by a group of students from the School of Engineering, Universiti Sains Malaysia in Pulau Burung landfill. From the literature, it has been indicated by most researchers that organic waste comprises of more than 40% of the total municipal solid waste (MSW) generated in Malaysia and the total waste generation in all states increases annually (Adi and Noor, 2009; Hamid et al., 2004; Pariatamby et al., 2009; Yusoff and Zakaria, 2012).

This problem is exacerbated by the existing solid waste management (SWM) in Malaysia. It has been reported in the literature that approximately 98% of the total waste generated in Malaysia is being disposed to landfills (Hamid and Pariatamby, 2009). A study has cited that approximately 75% of MSW collected from all states in Malaysia is being disposed to 130 landfills and dumps while 20% waste is burned or dumped into rivers or at illegal sites, and only 5% is recycled (Pariatamby and Hamid, 2006). An alternative to SWM such as a composting method is a practical way to manage the municipal solid waste in Malaysia due to the high proportion of organic and food wastes.

The disposal of high volume of organic wastes at landfills produce adverse environmental impacts associated with the disposal of organic wastes include the emission of greenhouse gases, contamination of the water sources by leachate and malodour problem due to anaerobic degradations. Therefore, the recovery of a large proportion of food waste through composting may significantly mitigate the adverse effect to the environment by reducing the volume of waste, mitigating the emissions of greenhouse gases, reducing the generation of leachate at landfills and recycling of nutrients to the soil system (Abdul Jalil, 2010; Oh et al., 2010). Additionally, the disposal of MSW at landfills particularly in the urban areas is no longer a viable option due to the escalated land prices, spatial scarcity and the increasing volume of waste generated (Yusoff & Zakaria, 2012). An alternative method is required to manage MSW, such as composting which is a feasible option in managing the high volume of organic and food waste generated (Adhikari et al., 2009).

1.2 Statement of the problem

Composting can be a reliable technology for organic waste stabilization, which subsequently turns it into value-added soil amendments. However, one of the major drawbacks in composting is long stabilization period. In THM composting, indigenous microorganisms cultured from local fermented food products are used as microbial inoculums to accelerate the biostabilization process of municipal organic waste. The method has been implemented widely around the regions of South East Asia as a means of solving problems associated with municipal solid wastes with the participation of respective municipalities (IGES, 2009). In the Malaysian context, THM composting has been widely practiced in the recent years: in Sibu, Sarawak (Hii, 2010), Kampar, Perak (Tan, 2010) and Penang (The Star, 2011).

This method is gaining popularity because of its practical implementation using local materials and rapid breakdown of organic wastes using microbial inoculums. In the literature, general discussions of THM as a composting method in managing SWM have been provided by several researchers (Damanhuri et al., 2014; Kurniawan and de Oliveira, 2014; Kurniawan et al., 2013; Puppim de Oliveira et al., 2013; Premakumara, 2013; Siriratpiriya, 2014 and Vazquez-Brust et al., 2014). However, the studies only provide general descriptions of THM as a composting method and strategies of managing solid waste in Asian cities. Despite its wide application, THM has not received wide attention among researchers particularly from the domain of natural science especially on the evaluation of the maturity and stability of its end products.

Maturity refers to the degree or level of completeness of the composting process and used is as an indicator for plant-growth potential or the presence of phytotoxic compounds so that its application as a soil conditioner does not have a negative effect on seed germination or plant growth (Iannotti et al., 1994; Bernal et al., 2008); whereas stability of composts is defined as the degree to which the organic fractions in composts have been stabilized during the process (Kalamdhad et al., 2008). In composting, compost is considered unstable if it contains a high proportion of biodegradable matter that may sustain high microbial activity. Compost is considered stable only when the material contains mainly of recalcitrant or humus-like matter which is normally abundant at the end of the composting process and could not sustain microbial activity (Kalamdhad et al., 2008).

In addition, the effect of using different microbial starters on the biostabilization process in THM has not been explored by researchers. In Surabaya, bacterial source is obtained from local materials include tempeh and tape (fermented rice and potato products). In Malaysia, the common fermented food products that can be obtained from the supermarkets and local sundry shops include *tempeh*, *tempoyak*, *tapai pulut* and *tapai ubi*. From the literature, the microbial composition of these fermented food products is different from one another; the predominance of fungal population in t*empeh* (Reed and Nagodawithana, 1995), lactic acid bacteria (LAB) in *tempoyak* (Leisner et al., 2002) and yeasts and lactic acid bacteria in *tapai* (Chiang et al., 2006). Different microbial biota in these fermented food products may therefore have varying effects on the decomposition process of organic wastes.

Therefore, the observation of maturity and stability of the biostabilization process and the use of fermented food products as microbial starters are important to determine the extent of biostabilization using THM and the physicochemical properties of the end product as soil conditioner. Findings obtained from a systematic research on THM composting also contribute towards the literature on the application of local knowledge in environment management, and for the development of suitable composting technologies based on the application of microbial inoculums.

1.3 Research objectives

The aim of this study is to determine the maturity and stability during the biostabilization of cafeteria waste using Takakura Home Method with different fermented food products as microbial starters. The specific research objectives formulated for this study are:-

1. To observe the microbial growth during the preparation of compost seed by evaluating the colony-forming units of total bacteria, total fungi and actinomycetes.
2. To evaluate the degree of compost maturity of the stabilized waste using physicochemical parameters namely temperature, pH, elemental analysis of carbon, nitrogen and C:N.
3. To evaluate the degree of compost stability of the stabilized waste using microbial parameters based on colony-forming units (CFU) of total bacteria, total fungi, actinomycetes and carbon dioxide evolution.

1.4 Scope of the study

The research was conducted to determine the feasibility of THM as a composting method based on the growth pattern of microbial population during the biostabilization of cafeteria waste and the maturity and stability of the stabilized waste. Maturity and stability indicators are important to determine the degree to which the organic fractions in composts have been stabilized (Kalamdhad et al., 2008) and the presence of phytotoxic compounds so that its application as a soil conditioner does not have a negative effect on seed germination or plant growth (Iannotti et al., 1994; Bernal et al., 2008).

Cafeteria waste was used as the feed material for the composting process. The waste was collected from several cafeterias within the university compound and was segregated before being fed into compost reactors. To evaluate the practicality of THM on the biodegradation of waste, protein-based sources such as meat products were included. During the segregation process, only plastics and other non-edible wastes such as tea bags were removed. The compost seed was prepared by using three different sources of commonly found fermented food products in Malaysia, namely *tempeh* (fermented yellow beans), *tapai pulut* (fermented glutinous rice) and *tempoyak* (fermented durian hull). The fermented food products were obtained from the local supermarket and sundry store. The overview of the research scope is depicted in Figure 1.1.

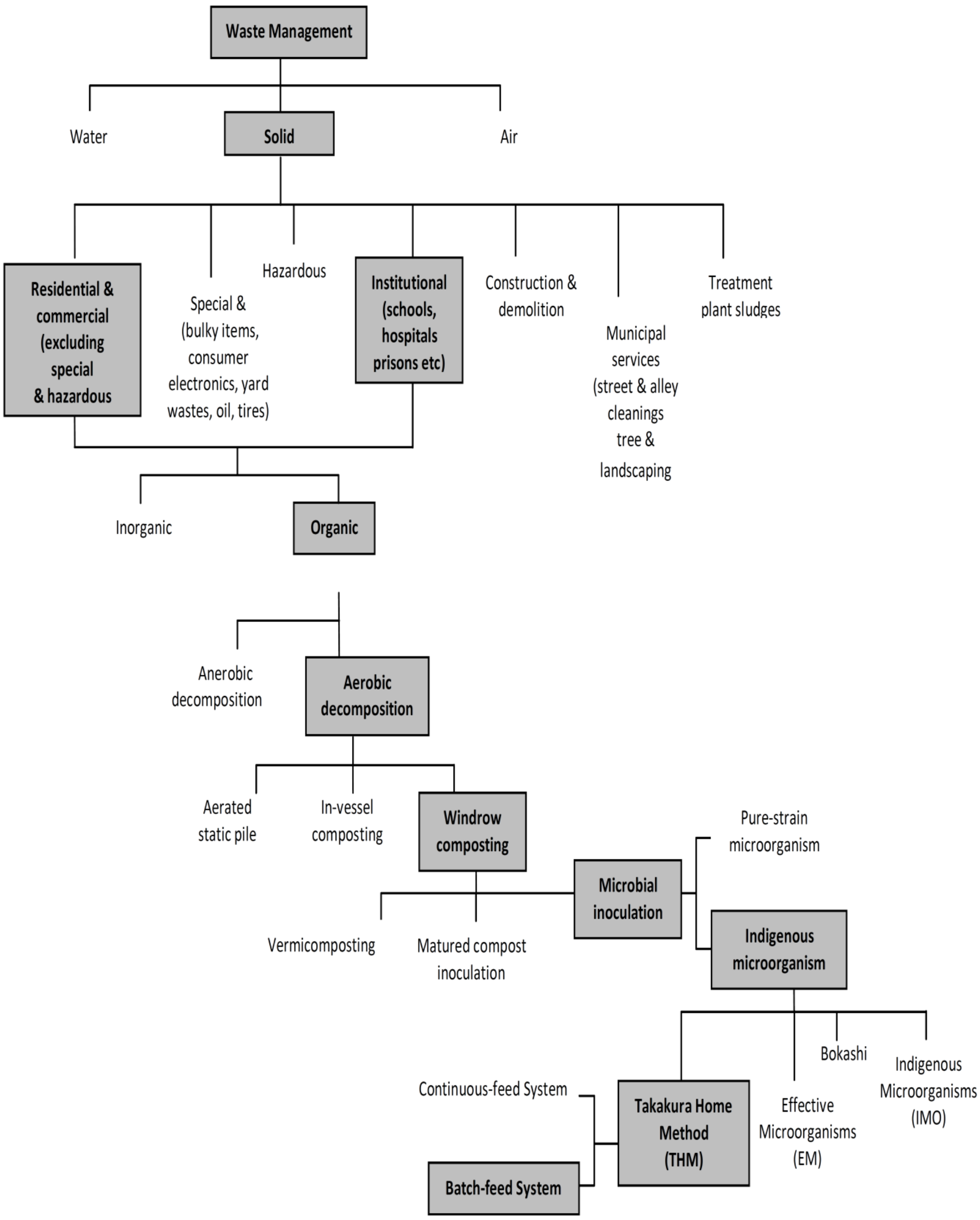

Figure 1.1 Scope of research

1.5 Chapter summary

In this chapter, the aim of the research in determining the feasibility of Takakura Home Method as a biostabilization method for cafeteria waste has been presented through the determination of problem statement, research objectives and the scope of the study. This chapter has also outlined the motivation of using scientific approach in interrogating THM, a method developed based on the use of local knowledge and resources, as a means for waste stabilization. In the following chapter, a more comprehensive discussion on the relevant theories from the literature will be presented.

CHAPTER 2

REVIEW OF LITERATURE

2.0 Introduction

In this chapter, a comprehensive literature review on topics and theories related to the present study are presented, which include municipal solid waste management, composting processes, the role of microorganisms and microbial inoculation in composting. As the principal topic of research is the implementation and development of THM model based on the local knowledge, the use of fermented food products as microbial inoculums and the biochemical mechanisms during THM composting is given a special emphasis. The use of standard and uniformed terms is important in the aspect of planning and managing wastes thus definitions for the principal terms used in the present study such as “solid waste”, “food waste” and “composting” are given a detailed description.

2.1 Overview of waste management

Although nature has the capacity to degrade the impact of unwanted residues eliminated from the human waste stream, ecological imbalances will inevitably occur when the waste generation exceeds the natural assimilation capacity of the environment. To mitigate the adverse effect of waste generated to the environment, various waste management and treatment options have been applied and can be divided into three main domains; (i) solid waste management (SWM); (ii) wastewater treatment; and (iii) air pollution treatment (Williams, 2005).

2.1.1 Definition of solid waste

There is a broad definition of waste found in the literature. The term “waste” can be subjective as one’s waste can be regarded as a resource by another. However, the term “waste” in the regard of waste management and environmental engineering adhere to a strict legal definition. The categorization of solid waste is a tedious subject, yet the determination of solid wastes according to its composition is crucial to implement cost-effective management strategies beneficial to both public health and the environment. The compliance of waste to regulation also allows for the formulation and planning of waste.

According to the EU’s Waste Framework Directive 1975, waste can be defined as “any substance or object which the holder discards or intend to discard” (Williams, 2005). In this definition, “holder” is referred to the waste producer or possessor, and “producer” as the person or institution that involved in the activities of producing and processing of waste, or altering the composition of waste. The types of waste composed of three main classes; solid waste, wastewater and polluted gas. Solid waste is regarded as a consequence of life; the use of natural resources by human and animals has resulted in the disposal of waste materials (Koroneos and Nanaki, 2012). The term “solid waste” refers to both heterogeneous discards from the households as well as the more homogeneous composition of disposed materials from the industry and agriculture (Tchobanoglous and Kreith, 2002). Similarly, a strict, uniformed definition of solid waste is crucial for the planning and management of solid waste.

According to the U.S. Code of Federation Regulations, solid waste is defined as “garbage, refuse, sludge and other discarded solid materials resulting from industrial and commercial operations and from community activities. It does not include solids or dissolved materials in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial wastewater effluents, dissolved materials in irrigation return flows or other common water pollutants” (Pichtel, 2005). Solid waste comprises of a comprehensive range of refuses; from the typical discards from the households such as garbage, old newspapers, packaging materials and yard wastes to bulky appliances such as old furniture, dead trees, junked automobiles, street sweepings and construction debris (Tchobanoglous and Kreith, 2002). Solid waste also comprises of refuses from the mining and mineral operations that produce wastes in the form of tailings, slag and other solid wastes (Durucan et al., 2006) as well as wastes arisen from the agriculture, such as crop residue, dead livestock and livestock wastes (Sandars et al., 2003).

Solid wastes can be classified according to the type of materials and waste characteristics. Pichtel (2005) has listed nine major classes of wastes according to its generation point: municipal, hazardous, industrial, medical, universal, construction and demolition, radioactive, mining and agriculture. Similarly, Tchobanoglous and Kreith (2002) have stated that sources of solid wastes produced are subjected to land use and zoning. Therefore, based on this, solid waste is classified into the following categories: residential, commercial, institutional, construction and demolition, municipal services, treatment plant sites, industrial and agricultural.

2.1.2 Management of municipal solid waste

Municipal solid waste (MSW) is defined as solids discarded by the end users of private households, public areas and small businesses and is typically collected and managed by the local municipalities (Ludwig et al., 2002). The main compositions of MSW comprise of paper and cardboard, organic wastes such as food and garden waste, plastics, metals, glass and textiles. However, the percentage of waste compositions in each country varies as it is subjected to many factors, such as socio-economic activities, types of the industry and extent of industrialization, geographic factors, climate, extent of urbanization and consumption, population density, legislative control, waste collection and management system, extent of recycling and public awareness (Williams, 2005). A large fraction of MSW is comprised of organic waste, especially in low income areas where a large portion of MSW produced is comprised of food waste (Ludwig et al., 2002).

In Malaysia, there has been an exponential increase of solid waste generation (Figure 2.1) where the major category consisted of domestic and food waste as reported by most literatures (Adi and Noor, 2009; Hamid et al., 2004; Pariatamby et al., 2009; Yusoff and Zakaria, 2012: Zamali et al., 2009). The average organic waste content in Malaysia was approximated to be 50% in the 1980s and 1990s and is mostly consisted of processed kitchen waste and food waste (Pariatamby et al., 2009). A study by EPU (Economic Planning Unit) in 2006 shows that 45% of all the wastes generated nationwide dumped in landfill composed of kitchen waste (Adi and Noor, 2009). In 2007, putrescible waste contributed approximately 46%, followed by paper waste (14%) and plastic based waste (15%) (Hamid et al., 2004).

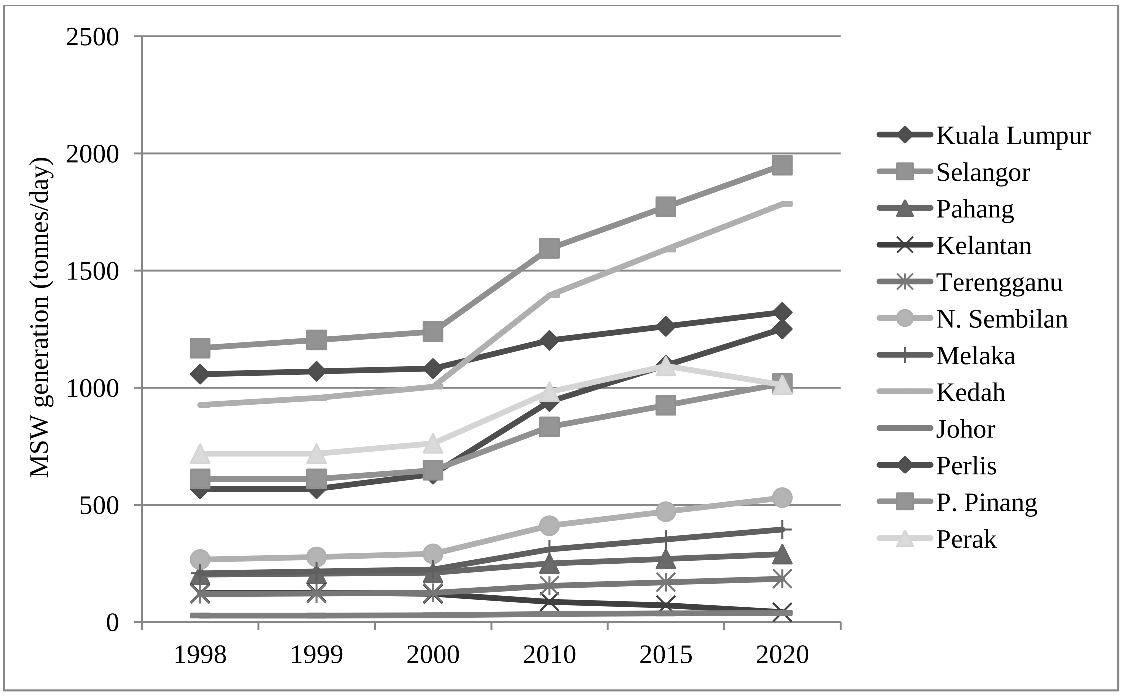

Figure 2.1 MSW generation and projected trends (Zamali et al., 2009)

For the practice of solid waste management in Malaysia, it has been reported that approximately 98% of the total waste is being disposed to landfills (Hamid and Pariatamby, 2009). Another literature has cited that approximately 75% of MSW collected is being disposed to 130 landfills and dumps while 20% waste is burned or dumped into rivers or at illegal sites, and only 5% is recycled (Pariatamby and Hamid, 2006). Table 2.1 shows the statistics of types and number of landfill sites in Peninsular Malaysia in 2001 (Johari et al., 2012). Coupled with the composition of food waste, the disposal of waste at unsanitary landfills may induce adverse environmental effects such as biogas production and groundwater contamination.

Table 2.1 Types of landfill sites in Peninsular Malaysia (Johari et al., 2012)

State	Open dump	Control dump	Sanitary landfill	Total
Johor	12	14	1	27
Kedah	9	5	1	15
Kelantan	12	2	0	14
Melaka	2	3	0	5
Selangor	8	6	0	14
Pahang	7	5	3	15
Perak	15	11	4	30
Perlis	0	1	0	1
Pulau Pinang	1	1	1	3
Terengganu	5	15	0	20
Negeri Sembilan	2	8	1	11
Total	73	71	11	155

A study by Abdul Jalil (2010) has suggested that household waste in Malaysia can be converted into vermicompost to reduce the amount of organic waste in the country which contributes to a cleaner environment and reduces the emission of methane gas at landfills. Another study suggested that composting can be incorporated at landfills with an integrated system of recycling to allow the optimization of waste reduction and reuse programs (Oh et al., 2010). Therefore, the recovery of a large proportion of food waste through composting may significantly mitigate the adverse effect to the environment due to the hazard caused by organic waste in unsanitary landfills. Table 2.2 indicates the current waste management methods in practice since 2002 and the proposed technologies to be used by 2020.

Table 2.2 Methods of waste disposal in Malaysia (Pariatamby et al., 2009)

Treatment	Percentage of waste disposed		
	2002	**2006**	**Target 2020**
Recycling	5.0	5.5	22.0
Composting	0.0	1.0	8.0
Incineration	0.0	0.0	16.8
Inert landfill	0.0	3.2	9.1
Sanitary landfill	5.0	30.9	44.1
Other disposal sites	90.0	59.4	0.0
Total	100.0	100.0	100.0

2.1.3 Management of food waste

The term 'cafeteria waste' is used instead of 'food waste' so that readers are well-informed of the point of waste collection. The term is used to refer to food waste produced from both over-consumption (left-over) and the food preparation process (kitchen waste include inedible wastes such as peels and tea bags). The study by Parfitt et al. (2010) has acknowledged definitions of food waste from three different sources; FAO (1981) has referred food waste as "wholesome edible material intended for human consumption, arising at any point in the food supply chain (FSC) that is instead discarded, lost, degraded or consumed by pests". The second definition is quoted from Stuart (2009) who has stated that food waste also includes "edible material that is intentionally fed to animals or is a by-product of food processing diverted away from the human food".

These definitions have referred food waste either as surpluses discarded as a result of over-consumption or by-products produced from the FSC which are still fit for human consumption. The third definition defines food waste in terms of energy. Smith (2004) has stated that food waste is "the gap between the energy value of consumed food per capita and the energy value of food needed per capita". From the biochemical point of view, food waste is comprised of putrescible organic materials subjected to biodegradation. According to Parfitt et al. (2010), the generation of food waste is mainly affected by two factors; technological advances or changes in the food processing and packaging industry and public attitude. Due to its high moisture content, composting is a feasible and popular way to treat food waste. With the use of suitable bulking agents for carbon: nitrogen (C:N) adjustments, composting reduces the volume and mass of organic solid waste, mitigates the emissions of greenhouse gases, reduces the generation of leachate at landfills and recycles nutrients to the soil system (Adhikari et al., 2009).

The selection of food waste as the feed material is based on the motivation that food waste comprises of a major fraction of the total solid waste generated in Malaysia. For example, in the state of Penang alone, it has been reported in 2012 that organic or food waste comprised of 57.4% (% weight) of total waste and 67.15% (% weight) based on combustible fraction (Yusoff and Zakaria, 2012). This is illustrated in Figure 2.2.

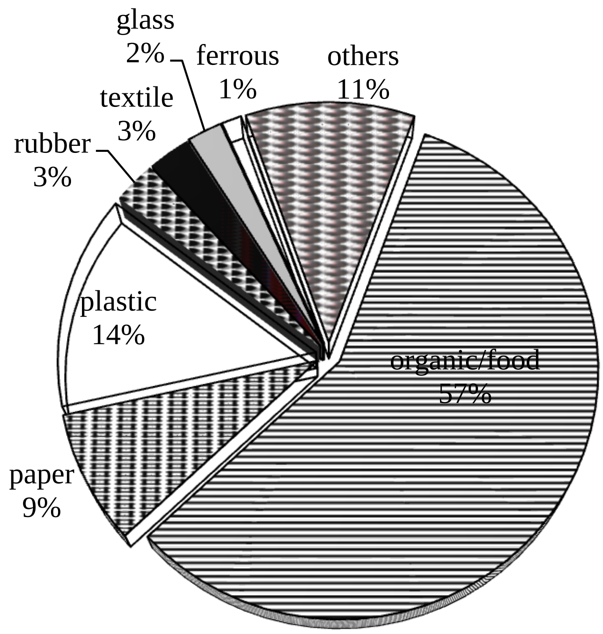

Figure 2.2 Composition of food waste in Penang in 2012 by % weight (Yusoff and Zakaria, 2012)

2.1.4 Feasibility of THM implementation in Malaysia

In the previous sections, an overview of the municipal solid waste management in Malaysia has been discussed. Statistics obtained from previous research show that there has been an exponential increase of solid waste generation in all states in Malaysia, and is projected to increase continuously up to year 2020. Focus of the research is placed on the organic fraction of municipal solid waste, where it has been reported in most literatures that the average organic waste content in Malaysia is approximated to be 50% in the 1980s and 1990s and is mostly consisted of processed kitchen waste and food waste. In the state of Penang alone, the organic fraction of municipal waste disposed at Pulau Burung landfill is estimated to be 57.4% (% weight) of total waste and 67.15% (% weight) in 2012 (Figure 2.2).

The review has also highlighted the waste management methods currently being practiced in Malaysia. It has been reported in previous studies that most of the waste generated nationwide in Malaysia is being disposed to landfills; this indicates that approximately 50% wastes being dumped in landfills comprised of organic waste. This can cause significant environmental impacts particularly in unsanitary landfills, such as greenhouse gas emission, groundwater contamination by leachate and malodour problem due to anaerobic digestion. In 2006, it has been indicated that 59.4% of the total waste generated waste were disposed at unsanitary landfills (Table 2.2).

From the review, problems identified from the solid waste management in Malaysia include the increase in solid waste generation, high composition of putrescible organic waste, and the lack of efficient management and proper disposal facilities for municipal solid waste. Through the implementation of alternative treatment method such as composting, a significant amount of solid waste being disposed in landfills could be diverted. For example, based on the example of Pulau Burung in Figure 2.2, approximately 57.4% of solid waste disposed at the site could be reduced.

2.2 Overview of the composting process

One of the most common ways to treat MSW is through biological and chemical conversion technologies. Biological conversion is commonly used for the transformation of the organic fraction of MSW. Biological processes include aerobic composting, low-solids anaerobic digestion, high-solids anaerobic digestion and aerobic composting (Tchobanoglous and Kreith, 2002). Composting is an aerobic, biological process achieved by the concurrent process of a complex consortium of microorganisms. It is the most widely-used method for treating the organic portion of MSW and transforming it into humus-like material known as “compost” (Liang et al., 2003).

Polprasert (1996) has provided three different definitions of composting. The first definition from Haug (1980) has stated “composting is the biological decomposition and stabilization of organic substances under conditions that bring about the thermophilic phase as a result of biologically-produced heat, with the end-product sufficiently stable for storage and land application without adverse environmental effects”. The other definition from Pereita-Neta (1987) which is widely-accepted in Europe have stated “composting is a controlled aerobic process carried out by successive microbial populations combining both mesophilic and thermophilic activities, leading to the production of CO_2, water, minerals and stabilized organic matter”. The author himself has defined aerobic composting as “the decomposition of organic wastes in the presence of oxygen, yielding CO_2, ammonia (NH_3), water and heat. The advantages of composting as solid waste management include (Pichtel, 2005)**:**

- Avoids undesirable reactions of organic waste at landfills. Anaerobic transformations will produce toxic gas unfavourable to the environment such as NH_3, hydrogen sulfide (H_2S) and methane (CH_4) gas.
- Avoids nitrogen (N) depression of plants. N is both required by plants and microorganisms for the manufacture of cell biomass. As the growth rate of microorganisms is faster, N will be taken up at a faster rate and results in

insufficient N for plants. Composting increases the N content in soil of incorporating N back into the cycle.

- Avoids leachate and the contamination of underground water. As organic waste especially food waste is high in moisture content, its disposal at landfills will result in the production of leachate. In situations where landfills are built without a proper leachate collection system, it will seep into the underground and contaminate the underground water source.

However, there are also disadvantages disassociated with composting, such as large initial capital requirement for the setup of composting plants, long period for the decomposition of organic wastes and the production of unstable end-products (Xiao et al., 2009). Other disadvantages include the emission of bioaerosols, requirement for large composting space and the difficulty to market the end product as soil amendments (Epstein, 1996). By taking both the advantages and disadvantages of composting into consideration, the method is considered to be a feasible technology for managing the municipal solid waste in Malaysia, given that landfilling is still the current and main disposal method of SWM in Malaysia which occupies a large amount of land that could otherwise be utilized for composting.

In addition, the space available for further waste compression in Malaysian landfills is also running out rapidly. For example in Pulau Burung, which is the only landfill in the state of Penang, it has been reported that the 62.4ha dumping site is expected to be fully saturated by 2021 and that at least 70% of the site has been used thus far (Phuah, 2010). The same problem is occurring for the landfill site in Sungai Siput, Selangor (Karupiah, 2012). The integration of composting as part of Materials Recovery Facilities (MRF) could be initiated to reduce the waste volume at landfills and to prolong the lifespan of landfills. due to its ability in reducing the volume of waste up to 40-50% and producing relatively stabilized products for storage and transportation (Xiao et al., 2009). In the following sections, the literature on anaerobic composting is omitted and only aerobic composting is reviewed due to the mechanism of THM as an aerobic decomposition process. The definition, influential factors, phases, process characteristics, biochemical properties and microbial groups that involved in the aerobic composting process is reviewed.

2.2.1 Composting as an aerobic degradation process

Aerobic composting is the decomposition of organic materials with the presence of oxygen (Yamada and Kawase, 2006). During composting, organic substrates are decomposed and stabilized under mesophilic and thermophilic conditions as a result of biologically-produced heat (Bertran et al., 2004). Aerobic composting has been applied to dispose a score of industrial and domestic wastes because it is inexpensive, simple and environmentally-sound in term of low energy consumption. Composting improves the handling and transportation of manure and waste by reducing its volume, water content and weight (Adhikari et al., 2009; Larney et al., 2000). An effective rate of biodegradation can be achieved by providing optimal conditions on the design and operating system of the composting process.

Temperature, moisture content, carbon-to-nitrogen ratio (C:N ratio), pH level, aeration rate and the physical structure of organic materials are important factors that influence the rate and efficiency of composting (Yamada and Kawase, 2006). Temperature plays an important role in the composting process, the maturity parameters, and the composting time in aerobic degradation of organic matter and has frequently been used to judge the efficiency and degree of stabilization and